Phase I Project Summary

Firm: MicroXact, Inc.
Contract Number: NNX09CF75P
Project Title: **Ultraefficient** Themoelectric Devices

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)

Thermoelectric (TE) devices already found a wide range of commercial, military and aerospace applications. Not only do TE devices have proven long-life performance reliability, withstand rigorous vibration, and are relatively insensitive to radiation and other environmental factors. However, commercially available TE devices offer limited conversion efficiencies, well below the fundamental thermodynamic (Carnot) limit due to limited Figure of Merit (ZT). While a number of new high-ZT materials have been proposed and/or demonstrated in the lab over the last decade, none of such materials was used in commercial devices due to the expensiveness of fabrication techniques required.

The team of MicroXact Inc and UCLA DRL proposed to develop a revolutionary ultrahigh efficiency thermoelectric material in the form of three-dimensional ñwellsò of Ge-Si Quantum Quantum Dot Superlattices (QDS) fabricated by a conformal coating of macroporous silicon (MPSi) pore walls with ultrahigh-vacuum Chemical Vapor Deposition (CVD) technique. The QDSs with short-range order exhibit very high ZT values. However, the thicknesses of fabricated QDS samples were limited to 100s of nm. With the proposed approach the QDSs with thickness from 10s to 100s of um will be cost-effectively fabricated by depositing only few 100s of nm QDS coating of MPSi pore wall.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)

Phase I project objectives were:
Objective 1: Develop the theoretical model of three-dimensional QDS array grown on macroporous silicon pore walls.
Objective 2: Prove the achievability of high thermoelectric conversion efficiency three-dimensional QDS array grown on macroporous silicon pore walls through modeling/simulations.
Objective 3: Prove the feasibility of key processes by demonstrating single layer QDS coating on macroporous silicon pore walls.
Objective 4: Develop strategies for product commercialization and transition to manufacturing.

Work proceeded through the following tasks:
Task 1: Develop the theoretical model of the proposed material (MicroXact).
Task 2: Design the thermoelectric material and device to meet 30% efficiency program goal and validate the performance through simulations/modeling (MicroXact).
Task 3: Develop the process of macroporous silicon fabrication with appropriate pore morphology (MicroXact Inc.).
Task 4: Develop the process of QDS growth on macroporous silicon pore walls and demonstrate conformal coating of pore walls with a single-layer QDS (UCLA DRL).
Task 5: Develop the concept of Phase II, commercialization strategy, and transition to manufacturing.

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)

An accurate model predicting thermoelectric properties of thermoelectric materials and devices utilizing semiconductor quantum dot superlattices (QDS) and quantum well superlattices (QWS) on macroporous silicon walls has been developed and validated. MicroXact Inc. through Finite Element simulations in Comsol environment verified that ZT of 4 and efficiency of 30% can be expected with thermoelectric material comprising Ge-Si QDS grown on pore walls, while ZT in the range of 2 to 2.2 and conversion efficiency in excess of 15% is feasible with Bi_2Te_3/Sb_2Te_3 superlattice grown on MPSi walls. MicroXact successfully fabricated MPSi templates and the team of MicroXact and Sundew for **the first time** demonstrated conformal coating of high aspect ratio macroporous silicon structure with antimony telluride. Verification of feasibility of this step clearly proving the feasibility of fabricating up to 500um thick thermoelectric materials and structures with ZT of excess of 2 (which was impossible with any state of the art technique below). This provides a solid foundation for Phase II development, optimization and demonstration of ultraefficient thermoelectric materials and devices. MicroXact also identified both the near term and long term applications and developed a preliminary concept of a commercialization plan for the proposed thermoelectric material and devices.

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)

The largest immediate NASA application of the proposed ultraefficient thermoelectric materials and devices is thermoelectric generators. The advantages of the proposed technology (unmatched efficiency combined with the small size and low weight) would provide the competitive advantage to MicroXact sufficient for successful market penetration. Other potential NASA applications include potential powering small devices from human thermal energy and refrigeration. Due to the unique benefits the proposed materials and devices are expected to penetrate these and other NASA applications. The proposed concept is expected to cause a significant impact on the cost, safety and reliability of future NASA missions.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)

The proposed ultraefficient thermoelectric materials and devices are expected to find applications in such fields as electronic device cooling (microprocessors, focal plane arrays, etc.), food storage/processing (wine cellers, Freon-free refrigerators), automotive and aviation industry (to enhance the fuel consumption). Due to the unique performance expected from proposed materials and devices all these markets can be potentially addressable with the proposed technology. The most promising market for initial penetration is believed to be the electronic component cooling market, where the benefits of the proposed technology (high efficiency combined with potentially reduced size) would provide the largest competitive advantage.

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